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FOR

RADIO FREQUENCY MODULATOR AND METHODS THEREOF

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BACKGROUND OF THE INVENTION

[0001] A radio transmitter may generate a radio frequency (RF) signal and may transmit it through an antenna into the surrounding. In order for a radio transmitter to be compatible with a communication standard, such as, for example, global system for mobile communication (GSM), a transmitter may have to occasionally lower the power of the transmitted signal to a low power level defined in that standard or to below that level.

BRIEF DESCRIPTION OF THE DRAWINGS

[0002] Embodiments of the invention are illustrated by way of example and not limitation in the figures of the accompanying drawings, in which like reference numerals indicate corresponding, analogous or similar elements, and in which:

[0003] FIG. 1 is a simplified block-diagram illustration of an exemplary communication system, in accordance with some embodiments of the present invention;

[0004] FIG. 2 is a simplified block-diagram illustration of an outphasing modulator, in accordance with some embodiments of the present invention; and

[0005] FIG. 3 is a simplified block-diagram illustration of another outphasing modulator, in accordance with some embodiments of the present invention.

[0006] It will be appreciated that for simplicity and clarity of illustration, elements shown in the figures have not necessarily been drawn to scale. For example, the dimensions of some of the elements may be exaggerated relative to other elements for clarity.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

[0007] In the following detailed description, numerous specific details are set forth in order to provide a thorough understanding of embodiments of the invention. However it will be understood by those of ordinary skill in the art that the embodiments of the invention may be practiced without these specific details. In other instances, well-known methods, procedures, components and circuits have not been described in detail so as not to obscure the embodiments of the invention.

[0008] It should be understood that the present invention may be used in a variety of applications. Although the scope of the present invention is not limited in this respect, the circuits disclosed herein may be used in many apparatuses such as the transmitters of a radio system. Radio systems intended to be included within the scope of the present invention include, by way of example only, cellular radio telephone communication systems, wireless local area networks that meet the existing 802.11a, b, g, and future high data-rate versions of the above, two-way radio communication systems, two-way pagers, personal communication systems (PCS), Bluetooth wireless communication systems, Zigbee wireless communication systems and the like.

[0009] Types of cellular radiotelephone communication systems intended to be within the scope of the present invention include, although are not limited to, Direct Sequence - Code Division Multiple Access (DS-CDMA) cellular radiotelephone communication systems, Global System for Mobile Communications (GSM) cellular radiotelephone systems, North American Digital Cellular (NADC) cellular radiotelephone systems, Time Division Multiple Access (TDMA) systems, Extended-TDMA (E-TDMA) cellular radiotelephone systems, wideband CDMA (WCDMA), General Packet Radio Service (GPRS) systems, Enhanced Data for GSM Evolution (EDGE) systems, 3G and 4G systems.

[0010] FIG. 1 is a simplified block-diagram illustration of an exemplary communication system, in accordance with some embodiments of the present invention. A communication device 2 is able to communicate with a communication device 4 over a communication channel 6. A transmitter according to embodiments of the present invention may be present in communication device 2 only or in communication device 4 only or in both communication devices 2 and 4. The

following description is based on the example of a transmitter according to one or another of the embodiments of the present invention present in communication device 2 only, although the scope of the present invention is not limited in this respect.

[0011] Although the scope of the present invention is not limited in this respect, the system shown in FIG. 1 may be part of a cellular communication system, with one of communication devices 2, 4 being a base station and the other a mobile station or with both communication devices 2, 4 being mobile stations, a pager communication system, a personal digital assistant and a server, etc. Communication devices 2 and 4 may include antennas 8 and 10, respectively, which may be, for example, dipole antennas, loop antennas, shot antennas dual antennas, omni-directional antennas or any other suitable antennas.

[0012] Communication device 2 may include a transmitter 12 that may include an outphasing modulator 14 and a power amplifier 16. Outphasing modulator 14 may receive a signal 18 that may contain information to be transmitted, and may modulate signal 18 using amplitude modulation, outphasing modulation, or both, and may output modulated radio frequency (RF) signals 20 and 22. Power amplifier 16 may receive modulated RF signal 20 and may amplify it, using for example, a first power amplifying element (not shown). Similarly, power amplifier 16 may receive modulated RF signal 22 and may amplify it, using for example, a second power amplifying element (not shown). Although the scope of the present invention is not limited in this respect, power amplifier 16 may combine these amplified signals by means of, for example, a transmission-line-combiner with reactive shunt terminations, and may output an RF signal 24 that may then be transmitted by antenna 8 over communication channel 6. Alternatively, the transmission-line-combiner may be replaced by a different combiner scheme, such as, for example, Hybrid BALUN or center tap inductor.

[0013] Transmitter 12 may optionally include one or more couplers 26 to sample RF signal 24 and to output one or more return signals 28 to carry samples of RF signal 24 to outphasing modulator 14. According to some embodiments of the invention, outphasing modulator 14 may optionally include a phase feedback path 30 to receive return signals 28 and to extract information about the phase of RF signal 24 from return signals 28. Additionally, outphasing modulator 14 may optionally include an

amplitude feedback path 32 to receive return signals 28 and to extract information about the amplitude of RF signal 24 from return signals 28.

[0014] Outphasing modulator 14 may include both phase feedback path 30 and amplitude feedback path 32, may include only one of them, or may not include either of them. In addition, phase feedback path 30 and amplitude feedback path 32, if included in outphasing modulator 14, may be activated or de-activated individually.

[0015] Communication device 4 may include a receiver 34. Receiver 34 may receive a modulated data signal 36 from communication channel 6 via antenna 10, and may, for example, extract the information contained in signal 18 by, for example, downconverting and demodulating signal 36.

[0016] It will be appreciated by persons of ordinary skill in the art that communication devices 2 and 4, and in particular transmitter 12 and receiver 30, may include additional components that are not shown in FIG. 1 so as not to obscure the description of embodiments of the invention.

[0017] Transmitter 12 may receive an average output power command 19 to set the average power of RF signal 24 accordingly. Although the scope of the present invention is not limited in this respect, transmitter 12 may receive average output power command 19 at, for example, substantially half-second time intervals, and average output power command 19 may command one of, for example, fifteen different average output power levels.

[0018] Various physical phenomena such as, for example, leakages of power from one circuit to another, or direct current (DC) offsets mismatches, may hamper the ability to decrease the power of the signal transmitted by antenna 8 to under a defined level or alternatively to turn off completely the power of the signal transmitted by antenna 8.

[0019] Outphasing modulator 14 may include attenuators to improve the ability to decrease the power of the signal transmitted by antenna 8 over communication channel 6.

[0020] Exemplary placement of such attenuators is detailed in FIGS. 2 and 3 for two alternative types of implementations of an outphasing modulator.

[0021] FIG. 2 is a simplified block-diagram illustration of an exemplary outphasing modulator, in accordance with some embodiments of the present invention.

[0022] Outphasing modulator 114 may receive a signal 118 that may contain information to be transmitted, and may output modulated RF signals 120 and 122 to a power amplifier (not shown). Outphasing modulator 114 may additionally receive return signals 128A and 128B that may carry samples of an RF signal at the output of that power amplifier. Moreover, outphasing modulator 114 may optionally receive an average output power command 119 to set the average power of the RF signal at the output of the power amplifier.

[0023] Outphasing modulator 114 may optionally include a phase feedback path 115 and may optionally include an amplitude feedback path 117. Outphasing modulator 114 may include both phase feedback path 115 and amplitude feedback path 115, may include only one of them, or may not include either of them. In addition, phase feedback path 115 and amplitude feedback path 117, if included in outphasing modulator 114, may be activated or de-activated individually.

[0024] Amplitude feedback path 117 may include an amplitude error detector 140 to receive signal 118 and return signal 128B, and to output an amplitude error signal 142 in relation to amplitude of signal 118 and amplitude of return signal 128B. Although the scope of the present invention is not limited in this respect, amplitude error detector 140 may have a controllable gain, and the amplitude of amplitude error signal 142 may be in relation to the gain of amplitude error detector 140.

[0025] Amplitude feedback path 117 may include an optional coupling block 144. Amplitude error detector 140 may receive return signal 128B directly or through optional coupling block 144. Optional coupling block 144 may include an optional programmable amplifier/attenuator 146. Although the scope of the present invention is not limited in this respect, optional coupling block 144 may include additional RF elements, and optional programmable amplifier/attenuator 146 may be located anywhere among these RF elements. For example, optional coupling block 144 may include an amplifier 148 and a harmonic filter 150. Optional programmable amplifier/attenuator 146 may be located before amplifier 148 (146A), between amplifier 148 and harmonic filter 150 (146B) or after harmonic filter 150 (146C).

[0026] Amplitude feedback path 117 may further include a function generator 152. Function generator 152 may receive signal 142 and may output a signal 154 in

relation to signal 142. Amplitude feedback path 117 may output an amplitude signal 156 related to signal 154.

[0027] Amplitude feedback path 117 may optionally include a function generator 112. Function generator 112 may receive signal 142 and may output a function signal 110 in relation to signal 142. Amplitude feedback path 117 may output an amplitude signal 158 related to function signal 110.

[0028] Although the scope of the present invention is not limited in this respect, in some alternative embodiments of the invention, function generator 152 and optional function generator 112 may receive signal 142 directly. In some other alternate embodiments of the invention, function generator 152 and optional function generator 112 may receive signal 142 through elements such as, for example, a variable gain amplifier 160 and/or a loop filter 162. Variable gain amplifier 160 and loop filter 162 may be connected in any order.

[0029] In addition, and although the scope of the present invention is not limited in this respect, in some alternative embodiments of the invention, amplitude signal 156 may receive signal 154 directly. In some other alternate embodiments of the invention, amplitude signal 156 may receive signal 154 through elements such as, for example, a variable gain amplifier 164 and/or a loop filter 166. Variable gain amplifier 164 and loop filter 166 may be connected in any order.

[0030] Furthermore, and although the scope of the present invention is not limited in this respect, in some alternative embodiments of the invention, amplitude signal 158 may receive function signal 110 directly. In some other alternate embodiments of the invention, amplitude signal 158 may receive function signal 110 through elements such as, for example, a variable gain amplifier 168 and/or a loop filter 170. Variable gain amplifier 168 and loop filter 170 may be connected in any order.

[0031] If amplitude feedback path 117 includes loop filter 162, then loop filters 166 and 170 may be optional. If amplitude feedback 117 includes loop filters 166 and 170, then loop filter 162 may be optional.

[0032] Phase feedback path 115 may include a phase error detector 172 to receive signal 118 and return signal 128A and to output a phase error signal 174 in relation to the phase of signal 118 and the phase of return signal 128A.

[0033] Phase feedback path 115 may include an optional coupling block 134. Phase error detector 172 may receive return signal 128B directly or through optional coupling block 134. Optional coupling block 134 may include an optional programmable amplifier/attenuator 136. Although the scope of the present invention is not limited in this respect, optional coupling block 134 may include additional RF elements, and optional programmable amplifier/attenuator 136 may be located anywhere among these RF elements. For example, optional coupling block 134 may include an amplifier 138 and a harmonic filter 132. Optional programmable amplifier/attenuator 136 may be located before amplifier 138 (136A), between amplifier 138 and harmonic filter 132 (136B) or after harmonic filter 132 (136C).

[0034] Phase feedback path 115 may further include a loop filter 176 and a signal generator 178. Loop filter 176 may receive phase error signal 174 and may output a filtered phase error signal 180. Signal generator 178 may receive filtered phase error signal 180 and may output a constant envelope signal 182 in relation to filtered phase error signal 180. According to some embodiments of the invention, signal generator 178 may additionally receive one or more control signals to set the amplitude of constant envelope signal 182. Although the scope of the present invention is not limited in this respect, constant envelope signal 182 may be an RF signal having a constant amplitude and variable phase.

[0035] Phase feedback path 115 may output a phase modulated carrier signal 183 related to constant envelope signal 182. Phase modulated carrier signal 183 may be equal to constant envelope signal 182 or may be derived from constant envelope signal 182 through an optional programmable amplifier/attenuator 190.

[0036] Outphasing modulator 114 may include an outphasing signal generator 184 to receive amplitude signals 156, 158 and phase modulated carrier signal 183 as inputs, and to output outphased modulated signals 208 and 210.

[0037] Outphasing signal generator 184 may include a phase splitter 192, a multiplier 194, a multiplier 196 and a sum-difference combiner 198.

[0038] Phase splitter 192 may receive phase modulated carrier signal 183 and may output phase shifted signals 200 and 202 having amplitudes substantially similar to the amplitude of phase modulated carrier signal 183. Phase shifted signal 202 may have a phase delay of substantially 90° relative to phase shifted signal 200.

[0039] Multiplier 194 may receive amplitude signal 158 and phase shifted signal 200, and may output a phase shifted modulated signal 204 related to a multiplication of amplitude signal 158 by phase shifted signal 200 with a first scaling factor. Similarly, multiplier 196 may receive amplitude signal 156 and phase shifted signal 202, and may output a phase shifted modulated signal 206 related to a multiplication of amplitude signal 156 by phase shifted signal 202 with a second scaling factor. For clarity, phase shifted modulated signals 204 and 206 are denoted "X" and "Y", respectively. The first scaling factor and the second scaling factor may be substantially equivalent or may be different. The scaling factors of multipliers 194 and 196 may be controlled, for example, by controlling a direct current (DC) supplied to multipliers 194 and 196, respectively.

[0040] Sum-difference combiner 198 may receive signals X and Y, and may output sum outphased modulated signal 208, denoted "(X+Y)", and difference outphased modulated signal 210, denoted "(X-Y)".

[0041] Modulated RF signals 120 and 122 may be equal to signals (X+Y) and (X-Y), respectively, or modulated RF signals 120 and 122 may be derived from signals (X+Y) and (X-Y) through optional programmable attenuators 212 and 214, respectively.

[0042] A non-exhaustive list of exemplary mechanisms that may interfere in achieving a desired low power level at the output of the power amplifier includes:

{a.} Multipliers 194 and 196 may have inherent DC offsets in their inputs that may not be equal. Consequently, when the values of amplitude signals 156 and 158 are such that phase shifted modulated signals 206 and 204, respectively, ought to be zeroed, at least one of phase shifted modulated signals 206 and 204 may not be zeroed. In addition, it may not be possible for both amplitude signals 156 and 158 to be zeroed at the same time, further interfering in zeroing phase shifted modulated signals 206 and 204.

{b.} Parasitic leakage mechanisms may result in phase modulated carrier signal 183 being induced into outphased modulated signals 208 and 210.

{c.} Parasitic leakage mechanisms may result in phase modulated carrier signal 183 being induced into the output of the power amplifier.

{d.} Parasitic leakage mechanisms may result in phase modulated carrier signal 183 being induced into the input to amplitude error detector 140.

{e.} Amplitude error detector 140 may have a limited dynamic range and may not handle correctly low power levels at the output of the power amplifier.

{f.} Phase error detector 172 may have a limited dynamic range and may not handle correctly low power levels at the output of the power amplifier.

[0043] According to some embodiments of the invention, the power levels of modulated RF signals 120 and 122 may be controlled by the attenuation of optional programmable attenuators 212 and 214 and/or by the controllable gain/attenuation of multipliers 194 and 196, to compensate for mechanism {a.}. The attenuation of optional programmable attenuators 212 and 214 and/or the controllable gain/attenuation of multipliers 194 and 196 may be set, for example, according to average output power command 119 once per an average output power command. Attenuators 212 and 214 may have, for example, two attenuation levels: 0db and 15db, although this is just an example and other sets of attenuation levels are also possible. Multipliers 194 and 196 may have, for example, two gain/attenuation levels: 0db and 15db, although this is just an example and other sets of gain/attenuation levels are also possible.

[0044] In addition, according to some embodiments of the invention, optional programmable amplifier/attenuator 190 may reduce the power levels of phase modulated carrier signal 183 to compensate for mechanisms {b.} and {d.}.

[0045] Moreover, according to some embodiments of the invention, signal generator 178 may have a controllable output amplitude to reduce the power levels of constant envelope signal 182 to compensate for mechanisms {b.}, {c.} and {d.}.

[0046] Furthermore, according to some embodiments of the invention, optional programmable amplifier/attenuator 146 may reduce the power level of return signal

128B to fit into the dynamic range of amplitude error detector 140 and to compensate for mechanism {e.}. For example, the dynamic range of amplitude error detector 140 may be in the range of approximately 30db-40db, and the desired average power of the RF signal at the output of the power amplifier may have, for example, one of fifteen levels. In such an example, optional programmable amplifier/attenuator 146 may have, for example, fifteen programmable amplification/attenuation levels, although in other examples programmable amplifier/attenuator 146 may have a different set of attenuation levels. In addition, variable gain amplifiers 160, 164 and 168 may have a set of gain levels to keep a substantially constant loop gain in accordance with the attenuation of optional programmable attenuator 146.

[0047] In addition, according to some embodiments of the invention, optional programmable amplifier/attenuator 136 may reduce the power level of return signal 128A to fit into the dynamic range of phase error detector 172 and to compensate for mechanism {f.}. For example, the dynamic range of phase error detector 172 may be in the range of approximately 30db-40db, and the desired average power of the RF signal at the output of the power amplifier may have one of fifteen levels. In such an example, optional programmable amplifier/attenuator 136 may have fifteen programmable amplification/attenuation levels, although in other examples programmable amplifier/attenuator 136 may have a different set of attenuation levels.

[0048] FIG. 3 is a simplified block-diagram illustration of an exemplary outphasing modulator 314, in accordance with some embodiments of the present invention. FIG. 3 is similar to FIG. 2, and the same reference numerals are used to refer to the same or similar components, which are not described again.

[0049] Exemplary mechanisms {b.}, {c.}, {d.}, {e.} and {f.}, as previously described in relation to outphasing modulator 114 may similarly exist with outphasing modulator 314, and may similarly interfere in achieving a desired low power level at the output of the power amplifier. Compensations for these exemplary mechanisms may be achieved using the same techniques described for outphasing modulator 114.

[0050] However, the DC offsets mismatch that causes mechanism {a.} in outphasing modulator 114 may be avoided in outphasing modulator 314 by using one multiplier instead of two, as detailed below.

[0051] Outphasing modulator 314 may receive signal 118 and return signals 128A and 128B, may output modulated RF signals 120 and 122, and may optionally receive average output power command 119.

[0052] Outphasing modulator 314 may optionally include phase feedback path 115 and may optionally include an amplitude feedback path 317. Additionally, outphasing modulator 314 may include an outphasing signal generator 316 and optional programmable attenuators 212 and 214.

[0053] Outphasing modulator 314 may include both phase feedback path 115 and amplitude feedback path 317, may include only one of them, or may not include either of them. In addition, phase feedback path 115 and amplitude feedback path 317, if included in outphasing modulator 314, may be activated or de-activated individually.

[0054] Amplitude feedback path 317 may output amplitude signal 358. Amplitude feedback path 317 may include amplitude error detector 140, loop filter 162, and may optionally include variable gain amplifier 160 and optional coupling block 144.

[0055] Outphasing signal generator 316 may receive amplitude signal 358 and phase modulated carrier signal 183, and may output outphased modulated signals 346 and 348.

[0056] Outphasing signal generator 316 may include a multiplier 320, a phase splitter 322, an amplifier 324, an amplifier 326, a limiter 328, a sum-difference combiner 330 and an optional function generator 332.

[0057] Multiplier 320 may receive amplitude signal 358 and phase modulated carrier signal 183, and may output an amplitude modulated signal 334 related to a multiplication of amplitude signal 358 by phase modulated carrier signal 183 with a scaling factor. The scaling factor of multiplier 320 may be controlled, for example, by controlling a direct current (DC) supplied to multiplier 320.

[0058] Phase splitter 322 may receive amplitude modulated signal 334 and may output phase shifted modulated signals 336 and 338 having amplitudes substantially similar to the amplitude of amplitude modulated signal 334. Phase shifted modulated signal 338 may have a phase delay of substantially 90° relative to phase shifted modulated signal 336.

[0059] Amplifier 324 may amplify phase shifted modulated signal 336 and may output a signal 340, denoted "Z". Amplifier 326 may amplify phase shifted

modulated signal 338 and may output a signal 342. Amplifiers 324 and 326 may have fixed gains or controllable gains.

[0060] Limiter 328 may receive signal 342 and may output a signal 344, denoted "T", related to signal 342 and to a limiting function. Although the scope of the present invention is not limited in this respect, the limiting function may be generated by optional function generator 332 that may be controlled by amplitude signal 358 and/or other signals (not shown).

[0061] Sum-difference combiner 330 may receive signals Z and T, and may output sum outphased modulated signal 346, denoted "(Z+T)", and difference outphased modulated signal 348, denoted "(Z-T)".

[0062] Modulated RF signals 120 and 122 may be equal to signals (Z+T) and (Z-T), respectively, or modulated RF signals 120 and 122 may be derived from signals (Z+T) and (Z-T) through optional programmable attenuators 212 and 214, respectively.

[0063] While certain features of the invention have been illustrated and described herein, many modifications, substitutions, changes, and equivalents will now occur to those of ordinary skill in the art. It is, therefore, to be understood that the appended claims are intended to cover all such modifications and changes as fall within the true spirit of the invention.